

LATE MIDDLE DEVONIAN DIASTROPHISM IN SOUTH-EASTERN AUSTRALIA.

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Introduction.

Several writers on the stratigraphy of the Devonian rocks of south-eastern Australia have implied that orogenic movement took place in this region between the deposition of Middle and Upper Devonian sediments, but no one has stressed its importance. Recent work on the Devonian sediments of the South Coast of New South Wales led the writer (1931) to a consideration of the correlation of these formations with others of Devonian age in New South Wales and Victoria, and to a study of the palaeogeography of the region during Devonian time.

As a result of this study the writer considers that the importance of late-Middle Devonian diastrophic movements has not been fully appreciated, and the present note is intended to call attention to this phase of Middle Palaeozoic orogeny, and to suggest its correlation with earth-movements of similar age in the Northern Hemisphere.

Of necessity the paper is based largely on the work of others, some reference to which is made in the text. A detailed bibliography of Australian Devonian geology up to the time of its publication (1922) is given in W. N. Benson's paper "Materials for the Study of the Devonian Palaeontology of Australia", and some later references may be found in the paper by the present writer (1931) on "The Stratigraphical and Structural Geology of the Devonian Rocks of the South Coast of New South Wales". The writer is indebted to Professor L. A. Cotton, M.A., D.Sc., Assistant-Professor W. R. Browne, D.Sc., Mr. L. L. Waterhouse, B.E., and Mr. W. S. Dun, for helpful discussion of various aspects of the paper, without in any wise committing them to agreement with all or any of the views expressed therein.

It is hoped that the paper will stimulate examination of the relations of the Middle and Upper Devonian sediments in those parts of the State which still await investigation.

Evidence of Diastrophism in South-eastern Australia.

Evidence of diastrophic movements between the deposition of Middle Devonian and Upper Devonian sediments in south-eastern Australia may be considered under the following headings: (i) Differences in the distribution of land and sea during the two epochs. (ii) Variation in the lithological characters of the sediments. (iii) Differences in the amount of folding in the two series. (iv) The visible angular unconformity between the two series in Victoria. (v) The palaeontological break.

(i). The distribution of land and sea during the Devonian period is indicated to some extent by the distribution of rock-outcrops of that age on the present

land-surface. The Lower Devonian consists chiefly of igneous rocks, the volcanic flows, tuffs and breccias of the Snowy River in Victoria. In the Walhalla-Wood's Point district in Victoria (E. W. Skeats, 1928) and in the Yass district of New South Wales (J. Mitchell and W. S. Dun, 1920) there is a conformable passage from Silurian into early Devonian sediments, suggesting that there was no important orogeny at the close of the Silurian. Devonian sediments overlie pre-Silurian formations with a marked unconformity.

Middle Devonian sediments occupy a somewhat similar but more extensive zone than that of the Lower Devonian; outcrops occur in Victoria at the Bemm River, Buchan, Bindi, Limestone Creek, Tabberabbera and the base of Mount Tambo. In New South Wales Middle Devonian sediments occur near Tumut, in the Murrumbidgee district near Yass, at Lake Bathurst Railway Station, Tarago, and in the region between Capertee and Mudgee. In the limestones of Kingsdale and Baw Baw, near Goulburn, formerly considered to be of Devonian age, the writer recently found a brachiopod, determined by Mr. W. S. Dun to be *Pentamerus knightii*, similar to that of Jenolan, and of Silurian age. No Middle Devonian sediments underlie the Upper Devonian of the south coastal portion of New South Wales, which was probably a land area during the Middle Devonian epoch. It is considered, therefore, that the Middle Devonian sediments were deposited in a gulf running from Gippsland, Victoria, northwards into New South Wales, including the Yass, Tarago, and Mudgee-Capertee districts.

Upper Devonian sediments overlie and extend beyond the Middle Devonian beds of Gippsland, Victoria, but no Upper Devonian beds are known in association with the Middle Devonian of the Upper Murrumbidgee near Yass. Upper Devonian sediments occur at intervals along the South Coast and adjacent tablelands of New South Wales, where they rest unconformably on pre-Devonian formations. They extend in a northerly and westerly direction through the central portion of the State, outcropping at Hartley, Mt. Lambie, Bathurst, Capertee, Wellington, Forbes, Parkes, Nymagee, Cobar, Canbelego and elsewhere.

This distribution of outcrops suggests some such relations of land and sea as those indicated in the palaeogeographic maps already given by the writer (1931, pp. 488-491), on which are shown the minimum areas covered by the sea.

The relation of the Devonian rocks of south-eastern Australia to those of the Tamworth, New England, district is obscure. On account of palaeontological evidence W. N. Benson (1922, plate xiii; 1923, pp. 25-26) suggests that they were formed in a gulf which probably was separated from that of the south-eastern province. Since newer formations occupy the region between the two provinces, it is unlikely that their palaeogeographic relations will ever be manifested.

The sea in which the Tamworth Devonian beds were deposited probably extended into Queensland and included the Silverwood-Lucky Valley area (H. C. Richards and W. H. Bryan, 1924).

(ii). The variation in the lithological characters of the sediments of Middle and Upper Devonian ages indicates important changes in the prevalent geographical and climatic conditions.

Middle Devonian sediments of Victoria, southern New South Wales and also of the Tamworth district consist of coralline limestones, indicating deposition under special conditions in warm, clear sea-water, with which are associated shales and tuffaceous and other igneous material.

The early Upper Devonian beds of Victoria and southern New South Wales consist of products of igneous action, together with red shaly and sandy sediments

of lacustrine or estuarine origin. These formations are followed by marine arenaceous sediments; no massive coralline limestones occur in the Upper Devonian of south-eastern Australia. In the New England district there is evidence of igneous activity in the early Upper Devonian Baldwin Agglomerates, which, however, occasionally show signs of water action (W. N. Benson, 1915, p. 578). The Barraba Series, of which the Baldwin Agglomerates are a basal stage, is apparently conformable with the Middle Devonian of the Tamworth district, and consists of arenaceous and argillaceous marine sediments, without any coralline limestones.

Thus there are very marked lithological differences between the Middle and Upper Devonian sediments, both in south-eastern Australia and in the New England district. The occurrence of thick deposits of coarse conglomerates, grits and sandstones of Upper Devonian age following the finer argillaceous and calcareous sediments of the Middle Devonian is itself an indication that earth-movements took place at the close of the Middle Devonian, which exposed a land-surface that was rapidly worn down in the succeeding epoch.

(iii). Differences in the amount of folding in the Middle and Upper Devonian sediments are modified to some extent by the contact-metamorphic effects of post-Devonian granitic intrusions. Nevertheless, viewed broadly, the Middle Devonian beds are more highly folded than those of Upper Devonian age. This is well illustrated in the Victorian occurrences at Tabberabbera (Howitt, 1875; Skeats, 1929), at the foot of Mt. Tambo (Whitelaw, 1899, p. 20), and elsewhere. In New South Wales, the Lower and Middle Devonian of the Upper Murrumbidgee, near Yass are thrown into a series of anticlines and synclines such as that illustrated by L. F. Harper (1909, Plate v).

The Middle Devonian limestones of the Tarago district are folded about meridional axes, the limbs of the folds having an average dip of 40 to 50 degrees (Carne and Jones, 1919, pp. 131-144). An interesting feature in this district is that the amount of folding in the Silurian beds at Baw Baw and Kingsdale, near Goulburn, is quite comparable with that of the Middle Devonian beds of the Tarago district. The exact field-relations of the two series have not yet been worked out.

In the Mudgee-Capertee district the (Middle) Devonian limestones trend more to the north-north-west, the amount of dip varying from 50 to 60 degrees (Carne and Jones, 1919, pp. 307-325).

Except locally in the neighbourhood of large igneous intrusions, Upper Devonian sediments of south-eastern Australia are not nearly so strongly folded as those of Middle Devonian age. In Victoria the Upper Devonian beds of North Gippsland are described by R. A. F. Murray (1877), A. W. Howitt (1875-77) and others as a gently dipping series. In the Eden district, New South Wales, they are horizontally bedded or gently folded (I. A. Brown, 1931), although to the north towards Yalwal (E. C. Andrews, 1901) the dips are greater on account of proximity to granitic intrusions and to the downwarped area of Permo-Carboniferous deposition.

The isolated outcrops over central New South Wales are gently folded as a rule. Thus, according to E. C. Andrews (1910, pp. 26-27) "the (*upper*) Devonian appears to have formed a gently-arched dome over the Forbes-Parkes district, the dome from Jemalong Gap to the Parkes waterworks being about 30 miles across". The limbs of this fold dip at angles of 10 to 15 degrees, "while the underlying (*Silurian*) rocks dip westerly at angles varying from 45° to 80°".

Greater dips are recorded by C. A. Süssmilch (1906, p. 137) for the Upper Devonian near Orange, but in the type-locality at Mt. Lambie the dips are not great, except within the contact-aureole of intrusive granite.

In describing the folding of the Upper Devonian of Canbelego and Cobar districts E. C. Andrews states (1915, p. 43): "This folding movement was peculiar, for, despite the fact that the beds were only folded gently, as a whole, nevertheless small patches of rock of Devonian age have been sharply compressed within the older sediments." . . . "In this connection it is interesting to note that the Devonian sediments in the western areas of the State as a rule have been folded only in a minor degree with sharp compression over very small areas." This variation in the degree of folding supports the belief that a period of diastrophism, peneplanation and subsidence occurred between the Middle and Upper Devonian.

(iv). The angular unconformity between the Middle and Upper Devonian sediments of Gippsland, Victoria, was recognized by early geologists (R. A. F. Murray, 1877; A. W. Howitt, 1875), and has been confirmed by later workers (H. Herman, 1898; O. A. L. Whitelaw, 1899; E. W. Skeats, 1929; and others). Good exposures showing almost horizontally bedded Upper Devonian unconformably overlying folded Middle Devonian beds occur along the Mitchell River below Tabberabbera, Victoria.

No such angular unconformity has yet been recorded in New South Wales. It has been suggested elsewhere (I. A. Brown, 1931) that the relations may be revealed in the Mudgee-Capertee or in the Goulburn-Tarago districts, where Middle Devonian limestones are in close proximity to Upper Devonian sediments. In the New England district, however, W. N. Benson (1915, p. 577) considers that there is no angular unconformity between the Barraba Series of Upper Devonian age and the underlying Middle Devonian.

(v). Palaeontological evidence is controlled to some extent by the conditions of sedimentation. Thus, during the Middle Devonian in south-eastern Australia, the conditions of limestone formation were favourable to the preservation of an abundant and varied marine fauna, which failed to survive the arenaceous and argillaceous conditions of the Upper Devonian.

Nevertheless it is significant that, of almost 280 species (besides Foraminifera and Radiolaria) comprising nearly 200 genera listed by W. N. Benson (1922), only about 20 forms are recorded as being possibly common to the Middle and Upper Devonian. The majority of these are indeterminate forms which may include several species, while the exact stratigraphical horizon and age of most of the others is open to some doubt.

Coelenterata and brachiopoda predominate in the Middle Devonian, whereas the Upper Devonian fauna consists largely of brachiopoda, lamellibranchiata and gasteropoda, the reef-building corals being absent from the Upper Devonian of south-eastern Australia. It is highly probable that the forms listed by W. N. Benson (1922, p. 105) from the Capertee region come from both Middle and Upper Devonian beds. Recently L. L. Waterhouse (1931, p. xlvii) has collected typical Middle Devonian fossils, including *Receptaculites*, *Loxonema*, and *Stromatopora* from the limestones of Coco Creek, Capertee.

Typically Upper Devonian fish, comparable with those of the Upper Old Red Sandstone of Scotland, are known from Taggerty and Freestone Creek, Victoria (E. S. Hills, 1931) and from the Forbes, Parkes and Canoblas districts, New South Wales (E. S. Hills, 1932), the genus *Bothriolepis* being present in each locality.

Although land plants made their appearance earlier, it was not until the Upper Devonian that they were at all abundant, when *Archacocalamites*, *Archacopteris*, *Sphenopteris* and several species of *Lepidodendron* appeared. These genera also occur in the Upper Devonian of Scotland. *Lepidodendron australe* is confined to the Upper Devonian series of south-eastern Australia. The writer has shown previously (1931) that in this area the beds containing *L. australe* form only the uppermost stage of the Upper Devonian, the *Lepidodendra* of the lower stages being specifically different.

In the New England district of New South Wales, W. N. Benson has found specimens of *Lepidodendron australe* near Nundle in the upper part of the Middle Devonian (Upper Bowling Alley Series) (1913, p. 579), and also near Tamworth, chiefly in the Barraba Series of Upper Devonian age, but extending downwards to an horizon which he believes "must be very close to the horizon on which the Moore Creek limestone would occur, if it were developed in this region" (1915, p. 581). The specimens, collected by E. F. Pittman and T. W. E. David (1899, p. 17, Pl. ii) came from a locality north-east of Tamworth, very close to the base of the (Upper Devonian) Barraba Series as mapped by W. N. Benson (1915, Pl. I).

The origin and affinities of the Devonian faunas of Australia have been discussed by W. N. Benson (1922).

Late Middle Devonian Diastrophism in other parts of the World.

Earth movements during the Devonian period have been recognized both in Europe and in North America. In Europe the marine Devonian were deposited in a geosyncline extending from the south of England eastward through central Europe. In some localities the stratigraphical relations are masked to a considerable extent by subsequent folding and metamorphism, but the sequence has been worked out in detail in the Rhine Valley, Belgium and elsewhere (F. Frech, 1897, Pt. 1, Vol. 1, pp. 34-55; J. W. Evans, 1929a, 1929b).

The Lower Devonian consists of shaly and sandy sediments, the Middle Devonian of limestones, marls and marly-shales characterized by the presence of *Calceola sandalina* in the lower portion and *Stringoccephalus Burtini* in the upper division. The lithological characters of the Upper Devonian vary considerably: there are some limestones near the base, but there is a greater amount of clastic material than in the Middle Devonian. The forms *Spirifer verneuilli* (*disjunctus*), *Rhynchonella cuboides*, *Goniatites*, *Clymenia* and *Cypridina* are characteristic.

Although there is no recorded angular unconformity between the Middle and Upper Devonian marine beds, there are lithological variations comparable in general with the Australian facies, and a definite palaeontological break occurs between the two series.

Probably the main geosynclinal area was continuously under the sea, but the marked variation in the distribution of Middle and Upper Devonian sediments denotes movements of the strand-line and possibly diastrophic movement along the continental margin.

This phase of Devonian orogeny is most clearly illustrated in the relations between the terrestrial, lacustrine and littoral Old Red Sandstone deposits of Devonian age in Wales, Scotland, and the Orkney Isles, and in Norway and Spitzbergen.

In Britain, according to A. Geikie (1903, p. 1007) the Old Red Sandstone has two subdivisions, of which "the lower passes down conformably into the Upper

Silurian deposits, the Upper shading off in the same manner into the base of the Carboniferous system, while they are separated from one another by an unconformability". The unconformable relations between the lower or middle and the upper Old Red Sandstone of Scotland have been recognized by all workers on the subject. The angular unconformity is illustrated in many well-known pictures and sections, such as those of the Orkney Isles (Geikie, p. 1011), The "Old Man of Hoy" (Grabau, p. 415), and the Pentland Hills (Wills, 1929, p. 295). That the break between the two series represents a considerable time interval is indicated by the palaeontological break and by the fact that "Fragments not only of the Lower Old Red Sandstone volcanic rocks, but also of the granite, dykes and sills intrusive in them can be recognized in the conglomerates of the Upper Old Red Sandstone" (J. W. Evans, 1929*a*, p. 142). This stratigraphic discontinuity is indicative of vast physiographic changes (*vide* L. J. Wills, 1929, pp. 291-309).

Somewhat similar relations obtain in North America, where outcrops of Devonian rocks have been grouped by H. S. Williams (1888) into four provinces, of which probably the most typical is the Eastern Continental Province. This extends from eastern New York in a general south-westerly direction down the Ohio Valley and southward into Tennessee, Mississippi, Alabama and Georgia. In this province the Middle Devonian includes the Onodaga and Hamilton with typical fauna. "In the early Upper Devonian time the sea retreated northward from its greatest southward extension of Hamilton time, and later again transgressed toward the south and south-west until it extended much farther than it had in the earlier period, this retreat and readvance being recorded in the unconformity at the base of the Upper Devonian black shale which is commonly exhibited south of the Ohio River and to some extent to the north of that stream" (S. Weller, 1909). Detailed descriptions of this unconformity occur in numerous papers in the State Geological Survey Bulletins, *The Bulletin of the Geological Society of America*, and in the *Journal of Geology*.

It is considered by some geologists that even where no angular unconformity is evident the enormous thickness of arenaceous deposits comprising the Portage and Chemung of Upper Devonian age is indicative of a previous period of orogenic movement, during which large areas were uplifted to provide a source of supply for the subsequent formations.

The Upper Devonian fauna is also distinct from that of the Middle Devonian, and consists largely of new immigrant elements closely allied to those of the Upper Devonian of Europe, in which *Hypothyris* (*Rhynchonella*) *cuboides*, *Manticoceras intumescens*, *Pugnax pugnax* (*Rhynchonella pleurodon*), and *Spirifera disjuncta*, are dominant forms (H. S. Williams, 1890; S. Weller, 1909).

Evidence of folding during the Devonian is recorded from eastern Canada and the United States of America. R. T. Chamberlin (1914, p. 330) classes the movements during the Devonian as the "Devonides" and includes the Gaspé folding between the Hamilton and the Mississippian, and the Appalachian folding after Hamilton time. E. Blackwelder (1914, p. 640) considers that the importance of this late Middle Devonian disturbance is sometimes ignored, although it is actually one of the major orogenic epochs in North America, and suggests for it the name "Brunswickian". Regarding the age, he states (p. 641): "Although there are some discrepancies in the evidence and hence some disagreement among writers on the subject, the testimony of the unconformities on the one hand, and of thick clastic formations on the other, indicates that the Brunswickian disturbance culminated after the middle of the Devonian but considerably before its close."

C. Schuchert (1910, 1930) and E. O. Ulrich (1911) also recognize a break between the Middle and Upper Devonian of North America. In view of this evidence, it is difficult to understand the conclusion of H. Stille (1924) that no important orogeny occurred at the close of the Middle Devonian.

Summary and Conclusions.

It is considered that there is evidence in south-eastern Australia that an important period of diastrophism occurred in Middle Palaeozoic time, during which the palaeogeography was entirely changed. That this orogeny occurred between the deposition of Middle Devonian and Upper Devonian sediments is indicated by (i) marked differences in the distribution of land and sea during the two epochs, (ii) variation in the lithological characters of the sediments of the two series, (iii) differences in the amount of folding of the two series, (iv) the visible angular unconformity in Victoria, (v) the palaeontological break.

At the end of the Middle Devonian the sea finally retreated from the gulf extending from eastern Victoria northwards into New South Wales, in which sediments had been deposited from Lower Palaeozoic until Middle Devonian times.

The south-coastal portion of New South Wales was compressed against the continental mass to the west, and the Middle Devonian beds of the Murrumbidgean gulf were folded in a meridional direction. Probably epeirogenic uplift accompanied this orogenic movement and a period of terrestrial peneplanation followed, during which the Middle Devonian folds were partially truncated before the deposition of Upper Devonian sediments.

During the early Upper Devonian a considerable amount of volcanic material was extravasated and lacustrine conditions prevailed along the new borders of the continent. Gradual subsidence followed and the sea transgressed over a large area of central and southern New South Wales and eastern Victoria, the greater part of which had not been under the sea since Silurian time. Only at the southern and possibly the northern extremities of the Middle Devonian gulf, that is, in the Tabberabbera, Victoria, and Capertee, New South Wales, districts, were the Upper Devonian sediments deposited over those of Middle Devonian age.

This area of Upper Devonian sedimentation gradually developed into the geosyncline of later Palaeozoic and Mesozoic deposition as distinct from the meridional gulf of earlier Palaeozoic time.

The late Middle Devonian diastrophism thus appears to have been one of the major orogenic epochs in the tectonic history of south-eastern Australia.

The change in the palaeogeography was accompanied by a change in the climatic conditions, which no doubt influenced the lithological nature of the sediments of Upper Devonian age. With these changes there was an immigration of a littoral fauna which was essentially distinct from that of the previous epoch. Somewhat different conditions prevailed in the New England district of New South Wales, where sedimentation was practically continuous from Middle Devonian until Middle Carboniferous time. Lithological and palaeontological variations comparable with those of south-eastern Australia occur within the sediments, but there is no angular unconformity in the sequence. Nevertheless, the Baldwin Agglomerate at the base of the Upper Devonian is possibly conglomeratic, and may represent a kind of "Flysch Facies" due to the rapid wearing down of a recently elevated landsurface, and thus may be indicative of earth-movements along the bordering continent. Somewhat similar conditions of sedimentation existed in

Queensland and a parallel tectonic history is also recorded. Thus W. H. Bryan (1925, p. 21) considers that "though they were preceded and followed by orogenic movements of great intensity, the Middle Palaeozoic periods themselves seem to be free from major earth-movements as far as Queensland is concerned".

Brief comparison with the relations of Middle and Upper Devonian sediments of Europe and North America suggests that conditions similar to those in south-eastern Australia existed also in the northern hemisphere, epi-Middle Devonian diastrophism being indicated in the marine sediments by lithological and palaeontological changes and in the terrestrial and littoral deposits by angular unconformity and palaeontological distinctions.

It is therefore considered that the diastrophism at the close of the Middle Devonian is of more than local importance, and that it may be regarded as one of the major orogenic epochs of the Palaeozoic era.

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